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AQUATIC MACROINVERTEBRATE DIVERSITY AND BIOMASS AS POTENTIAL INDICES OF ENVIRONMENTAL CONTAMINATION AT NATIONAL WILDLIFE REFUGES IN MONTANA

by
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ABSTRACT

Aquatic macroinvertebrate diversity and biomass were measured at wetland units on three National Wildlife Refuges in Montana and examined to determine if they were useful indictors of environmental contminant stress. Two chemically distinct wetland types were identified: Fresh and Oligosaline wetlands. The two wetland types differed in their invertebrate community dynamics. Oligosaline wetlands were more productive of invertebrates than were Fresh wetlands. We found that diversity measures based on field identification of invertebrate taxa were acceptable substitutes for measures based on identifications performed by a skilled taxonomist. Invertebrate biomass and diversity indices fluctuated so greatly with seasonal changes species composition and abundance that they would be of little value in detecting contamination events.

INTRODUCTION

Aquatic macroinvertebrates are important foods of resident and migratory birds, fish, and other wildlife using the wetlands of the National Wildlife Refuges (NWRs) in Montana. Their susceptibility to sediment- and water-borne contaminants makes them valuable indicators of the environmental health of wetlands (Cairns and Dickson 1971). Measurements of aquatic macroinvertebrate abundance and species composition can indicate the effects of contamination on other wildlife using the wetlands (Krueger et al. 1988).

Wetlands on NWRs in Montana typically consist of diked units supplied with water via irrigation ditches. The wetland units are vulnerable to contamination by agricultural chemicals (Eisler 1994), hazardous materials spills (Palawski et al. 1991), and irrigation drainage (Nimick et al. 1996). Contaminants from those and other sources are known to be toxic to aquatic macroinvertebrates (Cairns and Dixon 1971). The wetlands we studied were not known to have been impacted by any contaminants at concentrations acutely toxic to invertebrates. We adapted a simple and inexpensive technique used to study aquatic invertebrate community structure in lotic systems (Cairns and Dickson 1971) to monitor invertebrate diversity in shallow ponds on NWRs in Montana. We hoped that this simple technique would detect contamination-induced changes in aquatic invertebrate communities without the expense and delay necessary when invertebrates are identified by a skilled taxonomist. The objectives of our study were:

1) to determine water quality parameters at wetland units on three NWRs in Montana in the absence of known contaminant events;

2) to determine baseline invertebrate species diversity and biomass associated with variation in water quality; and

3) to determine if inexpert field determinations of diversity were comparable to laboratory determinations performed by a skilled taxonomist.

METHODS

We collected water quality data and aquatic invertebrates from eight wetland units at Benton Lake NWR, three units at Bowdoin NWR, and three units at Lee Metcalf NWR. Invertebrate samples were collected one night each month from May through October, 1994, within 6 days of the dark phase of the moon. Water quality data were collected the evening before and the morning after invertebrate collections.

Water Quality. We measured water temperature, specific conductance, pH, and dissolved oxygen at each wetland unit each month. During the May and August sample periods, we also collected raw water samples for determination of ionic composition and physical characteristics. The samples were analyzed for alkalinity, bicarbonate, calcium, chloride, total hardness, magnesium, potassium, total ammonia, nitrate plus nitrite, ortho-posphorus, sodium, and sulfate by the Montana Department of Health and Environmental Sciences Water Quality Laboratory, Helena, Montana.

Taxonomic Diversity (Field Determinations). We established four collection stations in each wetland unit and set one light trap (Espinosa and Clark 1972) at each station during each collection period. Each light trap consisted of a 6 volt electric flashlight and a 3.8 L plastic bottle with a funnel mouth attached to a metal fencepost placed no more than 10 m from shore in water no more than 1 m deep. Traps were set with most of the jar submerged, so that invertebrates entering the funnel when approaching the light were trapped in the jar. Lights were turned on in late afternoon or early evening, and the traps and their contents were retrieved the following morning.

We combined the contents of all four traps from a single wetland unit in a plastic container. The mixture of invertebrates and site water was stirred vigorously, and six, 250 ml subsamples were removed and placed in shallow pyrex pans with a sufficient volume of 70% isopropyl alcohol to immobilize the invertebrates. We counted 50 individual invertebrates in each subsample using the line-intercept method of Cairns and Dickson (1971). The transparent pans were underlain with sheets of lined paper, the lines forming transects for counting purposes. Starting at the origin of one arbitrarily selected line, the identity of each individual touching the line was recorded, until 50 individuals from the subsample had been counted. We were not sufficiently familiar with invertebrate taxonomy to assign each of the identified morphotypes to a species, but for purposes of diversity determination, we assumed that each of our morphotypes represented one taxon (cf. Cairns et al. 1968).

We determined the taxonomic diversity of the 300 individuals counted from each site using two methods. The Sequential Comparison Index (DI_t) of Cairns and Dickson (1971) is a simple count of the number of runs of taxonomically identical individuals in the sample, divided by the sample size, and then multiplied by the number of taxa:

$$DI_t = [(\text{Number of runs of a taxon})/n]*\text{Number of taxa}.$$

For example, if all 300 individuals counted were of the same taxon, $DI_t = (1/300)*1 = 0.0033$. If each of the 300 individuals was different, $DI_t = (300/300)*300 = 300$.

The second method was the Shannon-Wiener Index (Pielou 1966):

$$\hat{H}' = -\sum [(\text{Total of each taxon}/n)*(\ln (\text{Total of each taxon}/n))].$$

For example, if all 300 individuals counted were of the same taxon, $\hat{H}' = 0$. If each of the 300 individuals was different, $\hat{H}' = 5.7038$.

We also calculated $\hat{H}'$ for each site with cladocerans deleted from the input data, in order to avoid the swamping effect (Dickman 1968) on $\hat{H}'$ associated with the presence of one extremely abundant taxon among several taxa of low or moderate abundance. We calculated the percentage of cladocerans based on the counts of 300 individuals in each sample.

Biomass. When counts of individuals were completed for field diversity determinations, subsamples were returned to the combined sample container, and the entire sample from a single wetland unit was strained through a No. 30 Standard sieve (mesh size 0.059 cm). Wet mass of the material retained by the sieve was determined, and the sample was preserved in 10% formalin.

Taxonomic Diversity (Laboratory Determinations). The preserved samples were sent to Dr. D.L. Gustafson at Montana State University for taxonomic determination and counts of individuals. We calculated Shannon-Wiener diversity indices (with and without cladocerans), percent D. magna and D. pulex, and percent cladocerans using those taxonomic determinations and counts.

Data Analysis. We conducted an exploratory investigation of our data to determine if the distributions of the variables were normal and to select the appropriate statistical analyses. Because 6 of our 14 variables (i.e., DI_t, specific conductance, mass, and all 3 measures of cladoceran abundance) were not normally distributed based on the results of the Lilliefors test (Norušis 1993), we decided to analyze part of our data with nonparametric methods and part with parametric methods.

We included in our study-wide comparisons of water quality data, biomass, and diversity measures all data from wetland units from which we obtained data at any sampling date. We assumed the diversity measures derived from expertly identified taxa to be the most accurate and therefore compared all others with them. All study-wide comparisons were made using Spearman's rank correlation coefficient in STATGRAPHICS (Anon. 1987).

For comparisons within a Refuge over time, we included in our analyses only those data from wetland units that retained water throughout the study. Those statistical analyses were conducted using two-way analysis of variance (ANOVA) on untransformed data utilizing months as blocks. We believed that the ANOVA procedures would be robust enough to accomodate the departures from normality observed for DI_t and wet biomass. When significant differences were found among wetland units, we conducted multiple comparisons using Bonferroni 95% simultaneous confidence intervals. ANOVA procedures were conducted using SPSS (Norušis 1993).

RESULTS

Water Quality. Water temperature showed the expected seasonal cycle, with temperatures peaking in August at most sites (Tables 1-4). Specific conductance at Benton Lake NWR and Bowdoin NWR fluctuated with inputs from the water supply systems. Specific conductance remained relatively stable at Lee Metcalf NWR. We observed little change in pH at any of our sample sites other than Pond 3 at Lee Metcalf NWR. Dissolved oxygen readings taken in the morning appeared related to the pattern of water temperatures, but the two were only weakly correlated (Spearman's rho = -0.22, n = 66, p = 0.072).

We observed wide variation in chemical characteristics among the wetland units we sampled. The conductivity measures fell into three of the salinity categories defined by Cowardin et al. (1979): Fresh, Mesosaline, and Oligosaline. All units at Lee Metcalf NWR and the Lakeside Unit at Bowdoin NWR were Fresh wetlands (conductivity < 800 μS/cm). Unit 4A at Benton Lake NWR was classified as Mesosaline (conductivity = 8,000-30,000 μS/cm), and all other wetland units sampled were Oligosaline (conductivity = 800-8,000 μS/cm).

All wetland units at Lee Metcalf NWR and the Lakeside Unit at Bowdoin NWR were also classified in the Bicarbonate lake category of Barica's (1975) ionic composition classification system. All other wetlands sampled were classified as Sulfate or Bicarbonate-Sulfate lakes.

Chemical characteristics of the wetland units sampled at Bowdoin NWR and Lee Metcalf NWR showed little variation between the May and August sampling periods (Tables 5-12). At Benton Lake NWR, Units 1 and 2 showed general improvement (e.g., decreased sulfates) in August water quality compared to May water quality, but the other units retaining water in August showed little change.

Taxonomic Diversity (Field Determinations). Monthly measures of taxonomic diversity at all Refuges fluctuated greatly, in part due to changes in cladoceran abundance (Tables 13-16). Both measures of diversity were significantly and negatively correlated with percent cladocerans in the samples (for DI_t, Spearman's rho = -0.69; for $\hat{H}'$, rho = -0.72; n = 75, $p < 0.0001$ in both cases). However, inspection of scatterplots produced by the statistical software suggested that the relationship was nonlinear, with both measures maximized when cladocerans accounted for approximately 20% of the individuals counted and minimized when they accounted for 100%. We also found water temperature to be strongly correlated (Spearman's rho = 0.47, n = 71, $p < 0.0001$) and conductivity to be weakly correlated (Spearman's rho = -0.20, n = 71, p = 0.094) with $\hat{H}'$. Calculations of $\hat{H}'$ with cladocerans deleted did not vary as greatly, but reflected the same seasonal fluctuations (Tables 13-16).

We found no significant differences among $\hat{H}'$ values, with or without cladocerans, nor among DI_t values, from Units 1, 2, 4C, 5, and 6 (all units for which we had complete data) at Benton Lake NWR ($\hat{H}'$, two-way ANOVA, p = 0.196 with cladocerans, p = 0.162 without cladocerans; DI_t, p = 0.548). Nor did we find any significant differences among any of the diversity measures from the three sample sites at Lee Metcalf NWR ($\hat{H}'$, two-way ANOVA, p = 0.745 with cladocerans, p = 0.641 without cladocerans; DI_t, p = 0.653). However, at Bowdoin NWR, we found significant differences among units for all measures (two-way ANOVA, $\hat{H}'$ with cladocerans, $p < 0.001$; $\hat{H}'$ without cladocerans, p = 0.004; DI_t,

$p < 0.001$). For all measures, the Lakeside Unit was significantly different from the other two sample sites (Bonferroni 95% simultaneous confidence intervals).

Taxonomic Diversity (Laboratory Determinations). From the preserved samples, Dr. Gustafson and his colleagues identified and counted 11,032,325 individuals greater than 0.25 mm in size belonging to 171 invertebrate taxa. The ultimate taxa to which individuals could be assigned are listed in Table 17. Voucher specimens were preserved and placed in the Montana State University entomology collection. A complete list of all species taxa and their sites of collection is available from the Montana Field Office of the U.S. Fish and Wildlife Service.

We found no significant differences among $\hat{H}'$ values calculated with cladocerans included from the five units at Benton Lake NWR (two-way ANOVA, $p = 0.681$), nor from the three units at Lee Metcalf NWR ($p = 0.369$). We found a significant difference among units at Bowdoin NWR (two-way ANOVA, $p = 0.002$), with the Lakeside Unit differing significantly (Bonferroni 95% simultaneous confidence interval) from the other units.

We found no significant differences among $\hat{H}'$ values without cladocerans from the three units at Lee Metcalf NWR (two-way ANOVA, $p = 0.081$). Differences among units at Benton Lake NWR were marginally significant (two-way ANOVA, $p = 0.036$), but no differences were detected when using the Bonferroni procedure to conduct multiple comparisons. We found a significant difference among $\hat{H}'$ values without cladocerans at Bowdoin NWR ($p = 0.023$). The Lakeside Unit differed significantly (Bonferroni 95% simultaneous confidence interval) from the other units.

Comparisons of Diversity Indices. We found $\hat{H}'$[field] with cladocerans and DI_t to be most closely correlated with $\hat{H}'$[laboratory] with cladocerans among the diversity indices compared (for $\hat{H}'$[field], Spearman's rho = 0.73, $n = 76$, $p < 0.0001$; for DI_t, Spearman's rho = 0.73, $n = 76$, $p < 0.0001$). DI_t and $\hat{H}'$[field] with cladocerans were themselves closely correlated (Spearman's rho = 0.95, $n = 76$, $p < 0.0001$). All other diversity indices were less closely correlated with $\hat{H}'$[laboratory] with cladocerans, which presumably was the most accurate measure of diversity.

Biomass. Biomass of invertebrates collected in the light traps varied seasonally at all three refuges. Collected biomass peaked in spring and declined to its lowest point in August, recovering somewhat in early fall at the Oligosaline wetlands at Benton Lake NWR and Bowdoin NWR, but remaining low at the Fresh wetlands at Lee Metcalf NWR and Lakeside unit at Bowdoin NWR (Figure 1). Total wet mass collected was positively correlated with percent cladocerans (Spearman's rho = 0.45, $n = 71$, $p = 0.0001$) and with specific conductance (Spearman's rho = 0.53, $n = 71$, $p < 0.0001$).

We found no significant differences among wet masses collected from the five units at Benton Lake NWR for which we had complete data (two-way ANOVA, $p = 0.613$), among wet masses collected from all three sample sites at Bowdoin NWR (two-way ANOVA, $p = 0.111$), or among wet masses collected from all three sample sites at Lee Metcalf NWR (two-way ANOVA, $p = 0.323$).

Daphnia magna and *D. pulex* were the largest cladocerans on our study area and in many sample periods the most abundant. Their abundance was positively correlated with biomass (Spearman's rho = 0.69, $n = 75$, $p < 0.0001$) and appeared to influence strongly the observed biomass fluctuations (Figures 1 and 2).

DISCUSSION

Water Quality. Seasonal water quality fluctuations observed at Benton Lake NWR and Bowdoin NWR were typical of prairie wetlands (Swanson et al. 1988), with the exception of those units influenced by irrigation water inputs. The Lakeside Unit at Bowdoin NWR and all wetland units at Lee Metcalf NWR were chemically distinct from prairie wetlands. Maximum values for specific conductance and for sulfate, chloride, and potassium ion concentrations observed at Lee Metcalf NWR were lower than the minimum values reported by Swanson et al. (1988) in their survey of 176 prairie lakes.

Taxonomic Diversity. The line-intercept procedure used to collect data for field measures of diversity is length-biased (B. Esmoil, in litt.). That is, a nematode that might actually have a lower body mass than a daphnid would have a greater probability of being intercepted by a line simply because it is longer (Eberhardt 1978). Field measures of diversity would be expected to show higher values than unbiased laboratory measures of diversity, because the rarer but longer leeches, snails, nematodes, etc., would be counted more often than expected based on their true abundance. That was not the case in this study. Out of 150 comparisons, field measures of diversity were higher than laboratory measures only 42 times. We do not mean to suggest that no length bias existed, only that it had a minor influence on diversity calculations compared to our inability to identify taxa with certainty in the field.

We found a weak negative correlation between conductivity and $\hat{H}'$, but Wilhm and Dorris (1968), citing the unpublished work of Ransom, reported a correlation of -0.93 (statistical procedure not cited) between conductivity and $\hat{H}'$ in an Oklahoma reservoir. In our study, the effects of conductivity on diversity were confounded with the effects of all other seasonal variables.

The range of $\hat{H}'$ values reported here is typical of "areas of moderate [and] heavy pollution" (Wilhm and Dorris 1968) in freshwater streams. None of our $\hat{H}'$ values approached the value of 3.0 which Wilhm and Dorris (1968) expected "clean water areas" in freshwater streams to exceed. We cannot explain the seemingly low diversity at our sample sites, other than to suggest that our light traps might have attracted fewer species and more individuals of common species than would have been captured by a Surber sampler in a freshwater stream. That is, the invertebrate community subject to capture by a light trap from a prairie wetland was probably not as diverse as the set of taxa potentially sampled from a freshwater stream. We were unable to find any references to published studies reporting $\hat{H}'$ from lakes or ponds.

We suspect that the significant difference in diversity measures among wetland units at Bowdoin NWR is an accurate reflection of the lower invertebrate biomass produced by the Lakeside Unit and its very different water chemistry. At Benton Lake NWR, $\hat{H}'$ values were not sufficiently different at Unit 1 to distinguish it from the other units, even though it is known to be affected by high boron and selenium concentrations in water entering via Lake Creek.

Measures of diversity were less influenced by fluctuations in physical and chemical properties of the water within a wetland unit, which were minor, than by seasonal fluctuations in abundance of the aquatic invertebrates, particularly of cladocerans. Even the diversity indices resulting when cladocerans were deleted from the calculations fluctuated enough to disguise any but the most devastating effects of environmental

contamination. We cannot recommend measures of aquatic macroinvertebrate diversity as sensitive indicators of environmental contamination in these wetlands.

Biomass. Orians (1980) found a positive correlation between conductivity of lake water and biomass of emerging aquatic insects. We found a similar correlation between conductivity and biomass of invertebrates in the water column. However, the strength of our correlation seemed dependent upon the few sites at which high conductivity in early spring coincided with peak cladoceran abundance. Peak cladoceran abundance also occurred in spring at Lee Metcalf NWR and the Lakeside Unit at Bowdoin NWR, where we found very little seasonal variation in conductivity. Rawson and Moore (1944) suggested that invertebrate biomass peaked in Saskatchewan lakes at intermediate values of salinity (and conductivity), and declined above a level of salinity approximating a specific conductance of 3,100 μS/cm. Conductivity is probably an imperfect measure of the nutrients available to aquatic invertebrates, while being an accurate measure of toxic salinity when conductivity is high.

The patterns of seasonal cladoceran abundance, particularly of D. magna and D. pulex, that we observed at Lee Metcalf NWR and the Lakeside Unit at Bowdoin NWR (i.e., the Fresh wetlands) were most similar to those patterns reported from Arkansas (Applegate and Mullan 1969) and Kansas (Bruner 1984), where cladocerans also peaked in May-June and then declined to extreme rarity. A somewhat similar pattern was observed in North Dakota (Swanson et al. 1974), where cladocerans reached their peak in May and declined to approximately half the peak in June, July, and August. The patterns of abundance at Benton Lake NWR and most units at Bowdoin NWR (i.e., the Oligosaline wetlands) were more similar to those reported from Alberta (Lei and Clifford 1974) and Canyon Ferry Reservoir, Montana, (Wright 1965), where cladocerans exhibited two peaks of abundance, in June-July and again in August-September, with intermediate abundance between the peaks.

We do not know the causes of mid-summer cladoceran declines. Threlkeld (1979) suggested that predation by bluegills (Lepomis macrochirus), among other predators, might have been responsible for the midsummer declines he observed. Bluegills and bass (Micropterus spp.), also known to be predators of cladocerans (Carlander 1977), were found only in the four Fresh wetlands. They may have delayed the recovery of cladoceran populations in the Fresh wetlands, but could not have caused the decline observed in Oligosaline wetlands. The observed cladoceran declines may have been caused by seasonal changes in algal community structure (K. Nelson, in litt.).

Other invertebrates common in our collections, when studied elsewhere (Amphipoda: Cooper 1965, Menon 1969; Hemiptera: Istock 1973; Odonata, Hemiptera, Coleoptera: Swanson et al. 1974, Duffy and LaBar 1994), showed much less seasonal variation in abundance than did cladocerans. Fluctuations in abundance of those taxa, although muted compared to cladocerans, still showed strong seasonality. The amphipods and hemipterans studied elsewhere tended to reach their peaks of abundance in August, when water temperatures also peaked.

All but one of the sites sampled were highly productive during at least part of the period studied, usually in May. The Oligosaline wetlands were generally more productive than the Fresh wetlands. We believe that the observed patterns of standing stock biomass are typical of shallow, impounded wetlands in Montana. The greater availability of invertebrate foods to migratory birds during spring migration, and to a lesser extent

during fall migration, than during summer suggests that those wetlands may be of more value as stopover and breeding sites than as postbreeding and molting sites (Hohman et al. 1992). Indeed, Murkin and Kadlec (1986) reported significant correlations between nektonic and benthic invertebrate abundance and spring, but not fall, waterfowl use of wetlands.

Benthic invertebrates and sediment quality would be more appropriate subjects for future examinations of the potential effects of environmental contamination than the predominantly water-column taxa and water quality measures examined in this study (K. Nelson, in litt.). Benthic invertebrates are sensitive to contamination, and many taxa are sessile as adults and thus unable to move away from the monitoring site (Cairns and Dixon 1971). Their populations would presumably display reduced seasonal fluctuations in abundance under normal environmental conditions.

CONCLUSIONS

Diversity measures based on field determinations of taxa were acceptable substitutes for measures based on laboratory identifications of taxa. However, diversity indices fluctuated so greatly in response to seasonal changes in invertebrate abundance and species composition that they would prove of little value in detecting contamination events.

Fresh and Oligosaline wetlands differed in their invertebrate community dynamics. Invertebrate biomass was much greater in Oligosaline wetlands.

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Table 1. Benton Lake NWR (Units 1, 2, 3, 4A) water quality data collected in 1994. Temperature is presented as °C, conductivity as μS/cm, pH as standard units, and dissolved oxygen (D.O.) as mg/l.

	17 MAY-18 MAY	7 JUN-9 JUN	5 JUL-7 JUL	8 AUG-10 AUG	6 SEP-8 SEP	3 OCT-6 OCT
UNIT 1						
Temperature	12.9	15.2	14.2	20.0	15.2	7.7
Conductivity	12,710	1,170	2,030	2,640	840	951
pH	8.7	8.7	NA[A]	8.8	8.5	8.8
D.O. Evening	NA	12.9	11.8	14.4	12.8	14.1
D.O. Morning	9.3	9.4	NA	1.0	9.5	9.6
UNIT 2						
Temperature	11.7	12.1	NA	19.7	15.8	6.5
Conductivity	4,080	1,710	NA	1,850	1,800	1,079
pH	8.2	8.7	NA	10.0	9.4	10.3
D.O. Evening	NA	13.4	NA	19.0	18.8	14.2
D.O. Morning	8.2	7.6	NA	8.5	14.4	12.1
UNIT 3						
Temperature	9.2	13.4	NA	NA	NA	8.5
Conductivity	3,620	3,910	NA	NA	NA	9,760
pH	8.3	8.8	NA	NA	NA	9.3
D.O. Evening	10.3	15.1	NA	NA	NA	16.3
D.O. Morning	8.0	4.4	NA	NA	NA	9.5
UNIT 4A						
Temperature	9.4	10.1	NA	NA	NA	NA
Conductivity	11,870	14,950	NA	NA	NA	NA
pH	8.1	8.1	NA	NA	NA	NA
D.O. Evening	10.5	10.3	NA	NA	NA	NA
D.O. Morning	6.9	6.6	NA	NA	NA	NA

[A] NA = Not available.

Table 2. Benton Lake NWR (Units 4B, 4C, 5, 6) water quality data collected in 1994. Temperature is presented as °C, conductivity as μS/cm, pH as standard units, and dissolved oxygen (D.O.) as mg/l.

	17 MAY - 18 MAY	7 JUN - 9 JUN	5 JUL - 7 JUL	8 AUG - 10 AUG	6 SEP - 8 SEP	3 OCT - 6 OCT
UNIT 4B						
Temperature	10.5	11.3	NA[A]	19.3	NA	7.9
Conductivity	5,130	5,800	NA	5,410	NA	1,705
pH	8.4	8.9	NA	8.8	NA	9.9
D.O. Evening	10.5	14.9	NA	7.2	NA	14.6
D.O. Morning	9.3	8.8	NA	2.7	NA	10.0
UNIT 4C						
Temperature	11.1	12.6	14.1	18.9	15.5	7.8
Conductivity	2,820	2,640	3,790	5,970	1,634	1,358
pH	8.2	9.2	NA	8.9	8.6	9.3
D.O. Evening	8.3	>20.0	12.4	13.9	10.7	12.3
D.O. Morning	6.7	10.6	NA	8.4	4.8	8.5
UNIT 5						
Temperature	9.8	13.0	NA	16.9	15.7	6.5
Conductivity	3,160	2,330	NA	3,310	1,258	1,253
pH	8.4	8.6	NA	9.3	9.1	9.6
D.O. Evening	12.5	13.9	14.7	10.2	18.7	17.4
D.O. Morning	8.0	6.2	NA	2.2	9.2	4.5
UNIT 6						
Temperature	10.7	12.9	NA	17.3	15.5	7.6
Conductivity	3,830	3,350	NA	2,300	1,506	1,687
pH	8.1	8.9	NA	9.2	8.9	9.1
D.O. Evening	10.2	17.1	NA	6.0	17.5[X]	17.8
D.O. Morning	7.3	8.2	NA	1.4	1.1	6.0

[A] NA = Not available.

[X] Reading was unstable between 17.0 and 18.0.

Table 3. Bowdoin NWR water quality data collected in 1994. Temperature is presented as °C, conductivity as μS/cm, pH as standard units, and dissolved oxygen (D.O.) as mg/l.

	17 MAY	7 JUN - 9 JUN	5 JUL - 7 JUL	8 AUG - 10 AUG	7 SEP - 8 SEP	3 OCT - 5 OCT
LAKE BOWDOIN						
Temperature	14.3	17.4	18.2	16.3	15.6	8.7
Conductivity	6,570	6,390	6,910	7,860	1,086	538
pH	9.1	7.5	9.6	9.4	8.9	8.0
D.O. Evening	9.6	10.0	7.6	15.0	>20.0	9.0
D.O. Morning	8.9	NA[A]	15.0	4.8	3.6	8.1
LAKESIDE						
Temperature	14.4	17.5	20.1	18.0	15.6	9.8
Conductivity	526	510	518	570	551	470
pH	8.0	NA	9.8	9.6	9.7	8.7
D.O. Evening	14.4	NA	5.2	>20.0	>20.0	13.1
D.O. Morning	10.2	NA	9.6	7.6	13.6	10.8
DRUMBO						
Temperature	11.4	12.2	15.2	19.5	16.1	6.7
Conductivity	4,330	4,510	5,730	6,710	3,900	3,330
pH	8.7	9.4	7.6	9.2	9.7	9.0
D.O. Evening	15.2	11.2	0.3	8.9	8.8	11.6
D.O. Morning	10.4	3.4	0.4	0.3	1.6	6.5

[A] NA = Not available.

Table 4. Lee Metcalf NWR water quality data collected in 1994. Temperature is presented as °C, conductivity as μS/cm, pH as standard units, and dissolved oxygen (D.O.) as mg/l.

	17 MAY	9 JUN	7 JUL	9 AUG	8 SEP	30 SEP
POND 2						
Temperature	9.2	9.9	11.2	12.5	11.4	10.8
Conductivity	341	305	252	261	284	304
pH	7.2	7.5	7.2	7.3	7.0	7.0
D.O. Evening	9.4[A]	12.2	12.0	11.6	5.4	15.7
D.O. Morning	9.5	8.2	8.5	6.2	6.5	6.1
POND 3						
Temperature	14.9	15.4	16.6	20.0	16.3	13.0
Conductivity	227	210	205	193	176	203
pH	7.4	9.1	7.9	8.8	8.1	6.8
D.O. Evening	6.2[A]	11.8	11.6	18.2	14.0	8.6
D.O. Morning	7.4	8.7	7.2	7.8	9.0	5.5
BARN SLOUGH						
Temperature	13.3	15.6	15.6	20.1	14.7	12.7
Conductivity	237	206	235	245	212	241
pH	7.6	7.3	7.2	7.4	7.1	7.2
D.O. Evening	10.4[A]	12.4	12.0	8.0	7.5	8.5
D.O. Morning	8.8	7.6	7.0	3.2	1.5	1.8

[A] D.O. meter was not functioning properly.

Table 5. Water chemistry data collected in May, 1994, from Benton Lake NWR.

	Unit 1	Unit 2	Unit 3	Unit 4A
Alkalinity (mg/l)	171	400	537	667
Calcium (mg/l)	122	199	79.3	330
Chloride (mg/l)	122.0	95.5	104.0	586.0
Total hardness as $CaCO_3$ (mg/l)	2,208	1,678	1,377	4,146
Potassium (mg/l)	11	13.6	15.3	27.7
Magnesium (mg/l)	462	335	286	806
Sodium (mg/l)	775	486	457	2,190
Total ammonia as N (mg/l)	0.05	0.02	0.1	0.17
Nitrate + nitrite as N (mg/l)	2.81	<0.01	<0.01	0.02
Ortho-phosphorus (mg/l)	0.004	0.075	0.342	1.039
Sulfate (mg/l)	3,666	2,016	1,664	3,200

Table 6. Water chemistry data collected in May, 1994, from Benton Lake NWR.

	Unit 4B	Unit 4C	Unit 5	Unit 6
Alkalinity (mg/l)	798	512	825	697
Calcium (mg/l)	78.6	114	25.8	81.8
Chloride (mg/l)	164.0	63.8	107.0	112.0
Total hardness as $CaCO_3$ (mg/l)	1,523	1,105	983	1,379
Potassium (mg/l)	16.9	11	14.9	16
Magnesium (mg/l)	322	199	223	285
Sodium (mg/l)	801	313	501	534
Total ammonia as N (mg/l)	0.04	0.18	0.1	0.04
Nitrate + nitrite as N (mg/l)	0.02	0.03	0.05	<0.01
Ortho-phosphorus (mg/l)	0.595	0.401	0.567	0.614
Sulfate (mg/l)	2,266	1,146	881	1,638

Table 7. Water chemistry data collected in May, 1994, from Bowdoin NWR.

	Bowdoin Lake	Lakeside Unit	Drumbo Unit
Alkalinity (mg/l)	585	173	590
Calcium (mg/l)	29.6	25.8	40.5
Chloride (mg/l)	198.0	7.5	51.9
Total hardness as $CaCO_3$ (mg/l)	1,203	130	608
Potassium (mg/l)	19.4	6.7	12
Magnesium (mg/l)	274	16	123
Sodium (mg/l)	1,950	50.6	812
Total ammonia as N (mg/l)	0.11	<0.01	0.01
Nitrate + nitrite as N (mg/l)	<0.01	<0.01	<0.01
Ortho-phosphorus (mg/l)	0.098	0.007	0.13
Sulfate (mg/l)	4,047	74.9	1,785

Table 8. Water chemistry data collected in May, 1994, from Lee Metcalf NWR.

	Pond 2	Pond 3	Barn Slough
Alkalinity (mg/l)	164	108	115
Calcium (mg/l)	48.4	28.8	32
Chloride (mg/l)	2.7	2.4	2.4
Total hardness as $CaCO_3$ (mg/l)	160	100	108
Potassium (mg/l)	3	2.8	2.7
Magnesium (mg/l)	9.5	6.9	6.9
Sodium (mg/l)	11.5	7.8	6.8
Total ammonia as N (mg/l)	0.02	0.14	<0.01
Nitrate + nitrite as N (mg/l)	0.59	0.02	<0.01
Ortho-phosphorus (mg/l)	0.041	0.029	0.014
Sulfate (mg/l)	<6	<6	<6

Table 9. Water chemistry data collected in August, 1994, from Benton Lake NWR.

	Unit 1	Unit 2
Alkalinity (mg/l)	455	212
Calcium (mg/l)	51.8	46.2
Chloride (mg/l)	55.8	34.8
Total hardness as $CaCO_3$ (mg/l)	937	593
Potassium (mg/l)	18.8	4.7
Magnesium (mg/l)	196	116
Sodium (mg/l)	298	222
Total ammonia as N (mg/l)	0.594	0.04
Nitrate + nitrite as N (mg/l)	0.01	<0.01
Ortho-phosphorus (mg/l)	0.13	0.164
Sulfate (mg/l)	965	746

Table 10. Water chemistry data collected in August, 1994, from Benton Lake NWR.

	Unit 4B	Unit 4C	Unit 5	Unit 6
Alkalinity (mg/l)	213	542	413	260
Calcium (mg/l)	152	118	67.8	58.4
Chloride (mg/l)	111.0	90.4	76.3	41.6
Total hardness as $CaCO_3$ (mg/l)	1,711	1,865	1125	846
Potassium (mg/l)	14.2	19.8	10.8	5.5
Magnesium (mg/l)	323	381	232	170
Sodium (mg/l)	797	915	427	268
Total ammonia as N (mg/l)	0.031	0.081	0.171	0.039
Nitrate + nitrite as N (mg/l)	<0.01	<0.01	<0.01	0.01
Ortho-phosphorus (mg/l)	0.056	0.915	0.586	0.187
Sulfate (mg/l)	2,810	2,730	1,425	975

Table 11. Water chemistry data collected in August, 1994, from Bowdoin NWR.

	Bowdoin Lake	Lakeside Unit	Drumbo Unit
Alkalinity (mg/l)	530	137	622
Calcium (mg/l)	27.9	12.3	22.4
Chloride (mg/l)	158.0	9.4	75.8
Total hardness as $CaCO_3$ (mg/l)	1,108	86	629
Potassium (mg/l)	19.1	8.3	19.6
Magnesium (mg/l)	252	13.5	139
Sodium (mg/l)	1,900	86	1,340
Total ammonia as N (mg/l)	0.054	0.021	0.048
Nitrate + nitrite as N (mg/l)	<0.01	<0.01	<0.01
Ortho-phosphorus (mg/l)	0.049	0.014	0.032
Sulfate (mg/l)	3,917	117	2,470

Table 12. Water chemistry data collected in August, 1994, from Lee Metcalf NWR.

	Pond 2	Pond 3	Barn Slough
Alkalinity (mg/l)	127	94	122
Calcium (mg/l)	35.2	22.3	32.8
Chloride (mg/l)	2.0	1.6	2.0
Total hardness as $CaCO_3$ (mg/l)	117	80	112
Potassium (mg/l)	2.5	2.3	1.8
Magnesium (mg/l)	7	6	7.2
Sodium (mg/l)	9.6	7.4	7.7
Total ammonia as N (mg/l)	<0.01	<0.01	0.025
Nitrate + nitrite as N (mg/l)	0.38	0.01	<0.01
Ortho-phosphorus (mg/l)	0.031	0.014	0.045
Sulfate (mg/l)	<6	<6	<6

Table 13. Benton Lake NWR (Units 1, 2, 3, 4A) diversity indices and total mass for light trap samples collected in 1994.

	17 MAY - 18 MAY	7 JUN - 10 JUN	5 JUL - 8 JUL	9 AUG - 10 AUG	7 SEP - 9 SEP	4 OCT - 6 OCT
UNIT 1						
Field						
Ĥ' with Cladocera	1.475	1.312	1.407	1.258	0.389	0.192
Ĥ' without Cladocera	1.478	1.301	1.956	1.258	1.727	1.359
DI_t	6.000	6.966	8.100	5.167	1.170	0.420
% Cladocera	47%	52%	62%	0%	93%	97%
Total mass (g)	332.6	143.1	54.0	48.0	167.5	82.7
Laboratory						
Ĥ' with Cladocera	0.994	1.439	1.324	2.488	1.511	0.642
Ĥ' without Cladocera	1.527	1.526	1.988	2.405	0.628	1.047
% Cladocera	77%	57%	75%	3%	83%	99%
UNIT 2						
Field						
Ĥ' with Cladocera	0.987	0.926	1.690	1.225	1.046	0.118
Ĥ' without Cladocera	1.496	1.768	1.981	1.589	0.617	1.011
DI_t	4.400	3.667	10.766	3.687	3.337	0.160
% Cladocera	73%	78%	50%	64%	32%	98%
Total mass (g)	265.7	464.4	238.7	121.3	95.3	58.2
Laboratory						
Ĥ' with Cladocera	0.906	0.769	1.434	1.336	1.700	0.965
Ĥ' without Cladocera	1.449	1.447	2.258	1.533	0.973	1.631
% Cladocera	79%	87%	66%	64%	37%	98%
UNIT 3						
Field						
Ĥ' with Cladocera	0.461	0.403	NA[A]	NA	NA	0.152
Ĥ' without Cladocera	0.100	0.883	NA	NA	NA	1.745
DI_t	0.730	0.784	NA	NA	NA	0.350
% Cladocera	84%	90%	NA	NA	NA	98%
Total mass (g)	545.7	480.1	NA	NA	NA	157.2
Laboratory						
Ĥ' with Cladocera	1.083	1.151	NA	NA	NA	0.843
Ĥ' without Cladocera	0.258	1.243	NA	NA	NA	1.550
% Cladocera	82%	90%	NA	NA	NA	99%
UNIT 4A						
Field						
Ĥ' with Cladocera	0.120	1.722	NA	NA	NA	NA
Ĥ' without Cladocera	0.410	1.550	NA	NA	NA	NA
Di_t	0.150	9.380	NA	NA	NA	NA
% Cladocera	98%	10%	NA	NA	NA	NA
Total mass (g)	766.3	194.8	NA	NA	NA	NA
Laboratory						
Ĥ' with Cladocera	0.353	1.720	NA	NA	NA	NA
Ĥ' without Cladocera	1.252	1.533	NA	NA	NA	NA
% Cladocera	98%	13%	NA	NA	NA	NA

[A] NA = Not available.

Table 14. Benton Lake NWR (Units 4B, 4C, 5, 6) diversity indices and total mass for light trap samples collected in 1994.

	17 MAY - 18 MAY	7 JUN - 10 JUN	5 JUL - 8 JUL	9 AUG - 10 AUG	7 SEP - 9 SEP	4 OCT - 6 OCT
UNIT 4B						
Field						
$\hat{H}'$ with Cladocera	0.876	1.500	1.704	NA[A]	NA	0.186
$\hat{H}'$ without Cladocera	0.704	1.302	1.556	NA	NA	0.451
DI_t	2.350	7.520	11.334	NA	NA	0.220
% Cladocera	66%	10%	7%	NA	NA	96%
Total mass (g)	687.8	515.1	109.1	NA	NA	258.7
Laboratory						
$\hat{H}'$ with Cladocera	1.271	1.609	2.422	NA?	NA	0.960
$\hat{H}'$ without Cladocera	0.773	1.279	2.332	NA	NA	1.102
% Cladocera	69%	17%	11%	NA	NA	97%
UNIT 4C						
Field						
$\hat{H}'$ with Cladocera	0.854	2.072	1.597	1.919	1.070	0.378
$\hat{H}'$ without Cladocera	1.139	1.956	1.597	1.919	0.679	0.624
DI_t	2.240	14.506	7.626	10.617	5.010	0.916
% Cladocera	75%	19%	0%	0%	43%	90%
Total mass (g)	772.7	126.3	120.9	104.2	58.2	682.0
Laboratory						
$\hat{H}'$ with Cladocera	0.788	2.080	2.100	2.416	1.613	0.326
$\hat{H}'$ without Cladocera	0.668	1.805	2.037	2.321	0.574	0.784
% Cladocera	73%	22%	1%	2%	54%	95%
UNIT 5						
Field						
$\hat{H}'$ with Cladocera	0.335	0.750	1.940	1.746	1.458	0.682
$\hat{H}'$ without Cladocera	0.998	1.868	2.315	1.746	1.335	1.388
DI_t	0.716	2.900	14.400	9.273	6.233	2.134
% Cladocera	93%	84%	46%	0%	42%	83%
Total mass (g)	782.0	407.0	78.3	67.2	60.0	47.4
Laboratory						
$\hat{H}'$ with Cladocera	0.467	0.555	2.321	2.166	1.444	1.160
$\hat{H}'$ without Cladocera	1.184	1.630	2.472	1.941	1.394	1.466
% Cladocera	97%	91%	61%	16%	55%	86%
UNIT 6						
Field						
$\hat{H}'$ with Cladocera	1.247	1.668	1.698	1.743	0.805	0.920
$\hat{H}'$ without Cladocera	0.923	1.575	1.698	1.726	0.317	0.495
DI_t	3.700	7.600	10.200	9.940	1.707	3.734
% Cladocera	22%	3%	0%	0%	26%	54%
Total mass (g)	173.6	248.2	103.7	180.3	204.1	350.6
Laboratory						
$\hat{H}'$ with Cladocera	0.763	1.483	2.052	2.042	0.962	0.840
$\hat{H}'$ without Cladocera	0.545	1.363	2.041	1.896	0.248	0.180
% Cladocera	7%	3%	0%	14%	36%	69%

[A] NA = Not available.

Table 15. Bowdoin NWR diversity indices and total mass for light trap samples collected in 1994.

	17 MAY	7 JUN - 9 JUN	? JUL - 6 JUL	9 AUG - 10 AUG	7 SEP - 8 SEP	4 OCT - 5 OCT
LAKE BOWDOIN						
Field						
$\hat{H}'$ with Cladocera	1.078	0.829	0.808	0.949	1.146	0.499
$\hat{H}'$ without Cladocera	1.063	1.190	1.279	1.583	1.224	1.104
DI_t	5.980	2.590	2.534	2.854	3.760	1.280
% Cladocera	61%	76%	78%	75%	61%	88%
Total mass (g)	393.4	1,260.3	389.5	136.1	95.1	236.8
Laboratory						
$\hat{H}'$ with Cladocera	1.122	0.488	0.825	0.568	1.401	0.806
$\hat{H}'$ without Cladocera	0.836	0.896	1.720	1.772	1.805	1.531
% Cladocera	77%	88%	81%	88%	61%	96%
LAKESIDE						
Field						
$\hat{H}'$ with Cladocera	2.017	2.410	1.980	1.665	1.376	1.624
$\hat{H}'$ without Cladocera	2.060	2.371	1.877	1.636	1.345	1.501
DI_t	16.450	14.080	12.320	7.900	7.760	7.700
% Cladocera	33%	19%	5%	1%	1%	5%
Total mass (g)	85.4	159.5	101.0	60.2	72.4	24.3
Laboratory						
$\hat{H}'$ with Cladocera	2.288	2.675	2.473	2.430	2.424	1.492
$\hat{H}'$ without Cladocera	2.064	2.509	2.346	2.334	2.307	1.621
% Cladocera	16%	31%	13%	4%	4%	72%
DRUMBO						
Field						
$\hat{H}'$ with Cladocera	0.458	0.953	0.872	1.159	0.767	0.360
$\hat{H}'$ without Cladocera	1.731	0.498	0.872	1.159	0.304	0.636
DI_t	1.440	3.617	3.197	3.680	1.980	0.480
% Cladocera	91%	48%	0%	0%	22%	91%
Total mass (g)	1,040.9	692.3	14.3	25.7	285.6	818.8
Laboratory						
$\hat{H}'$ with Cladocera	0.251	0.991	2.371	1.494	1.681	1.294
$\hat{H}'$ without Cladocera	1.646	0.666	2.371	2.028	0.983	0.610
% Cladocera	96%	55%	0%	60%	33%	93%

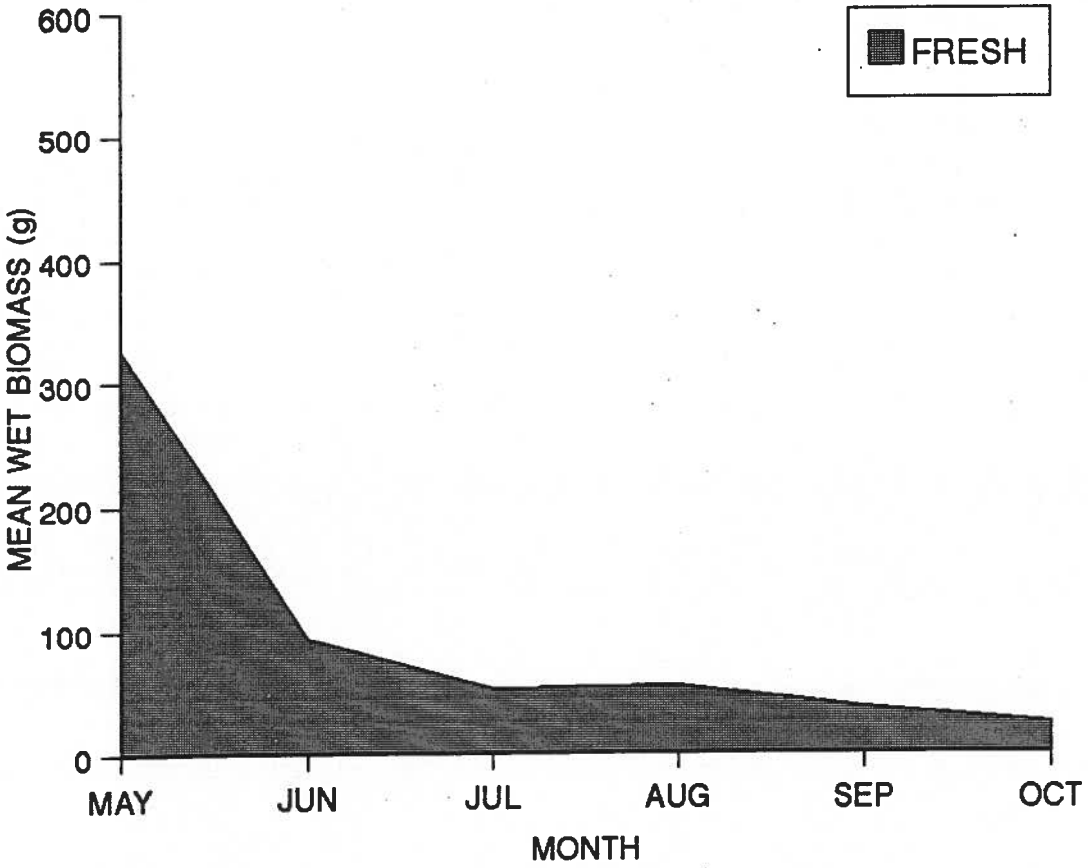
Table 16. Lee Metcalf NWR diversity indices and total mass for light trap samples collected in 1994.

	17 MAY	9 JUN	7 JUL	9 AUG	8 SEP	30 SEP
POND 2						
Field						
Ĥ' with Cladocera	0.373	0.884	1.770	1.835	1.613	0.791
Ĥ' without Cladocera	1.711	1.812	2.184	1.727	1.613	0.791
DI_t	1.094	3.533	13.490	10.350	7.800	2.660
% Cladocera	93%	79%	51%	5%	0%	0%
Total mass (g)	322.2	79.4	50.7	55.6	16.0	30.0
Laboratory						
Ĥ' with Cladocera	0.275	1.076	2.449	2.526	2.621	2.089
Ĥ' without Cladocera	1.897	2.321	2.335	2.404	2.496	2.095
% Cladocera	96%	87%	47%	30%	7%	56%
POND 3						
Field						
Ĥ' with Cladocera	0.449	1.629	0.879	1.280	1.324	1.402
Ĥ' without Cladocera	0.760	2.042	2.006	1.280	1.324	1.402
DI_t	1.000	7.800	4.247	5.550	4.457	5.700
% Cladocera	88%	54%	81%	0%	0%	0%
Total mass (g)	890.8	128.6	42.7	66.3	35.9	29.7
Laboratory						
Ĥ' with Cladocera	0.597	1.182	0.652	1.899	1.942	2.059
Ĥ' without Cladocera	0.778	1.965	2.122	1.874	1.942	2.016
% Cladocera	83%	80%	90%	1%	0%	1%
BARN SLOUGH						
Field						
Ĥ' with Cladocera	1.587	1.678	0.759	1.639	1.140	1.404
Ĥ' without Cladocera	1.506	1.754	1.919	1.544	1.140	1.373
DI_t	5.070	6.467	3.080	10.453	4.920	6.674
% Cladocera	39%	43%	84%	3%	0%	1%
Total mass (g)	8.3[A]	8.7	18.3	36.4	24.1	14.9
Laboratory						
Ĥ' with Cladocera	1.970	1.562	0.511	1.885	2.723	2.618
Ĥ' without Cladocera	1.629	1.311	2.104	2.010	2.547	2.430
% Cladocera	41%	35%	91%	49%	10%	18%

[A] Only three light traps were set at Barn Slough on 17 May 1994. Mass was treated as a missing value in statistical analyses.

Table 17. Ultimate taxa to which individual invertebrates could be assigned.

Class	Order	Ultimate taxon
Turbellaria	Tricladida	Genus
Gastropoda	Ctenobranchiata	Species
	Pulmonata	Species
Pelecypoda	Eulamellibranchia	Family
Hirudinea	Rhynchobdellida	Species
	Arhynchobdellida	Species
Insecta	Ephemeroptera	Genus or species
	Odonata	Genus or species
	Hemiptera	Genus or species
	Trichoptera	Genus or species
	Coleoptera	Genus or species
	Diptera	Family
Crustacea	Anostraca	Species
	Conchostraca	Species
	Podocopa	Order
	Calanoida	Order
	Cyclopoida	Order
	Harpacticoida	Order
	Cladocera	Genus or species
	Amphipoda	Species
Arachnida	Acari	Order



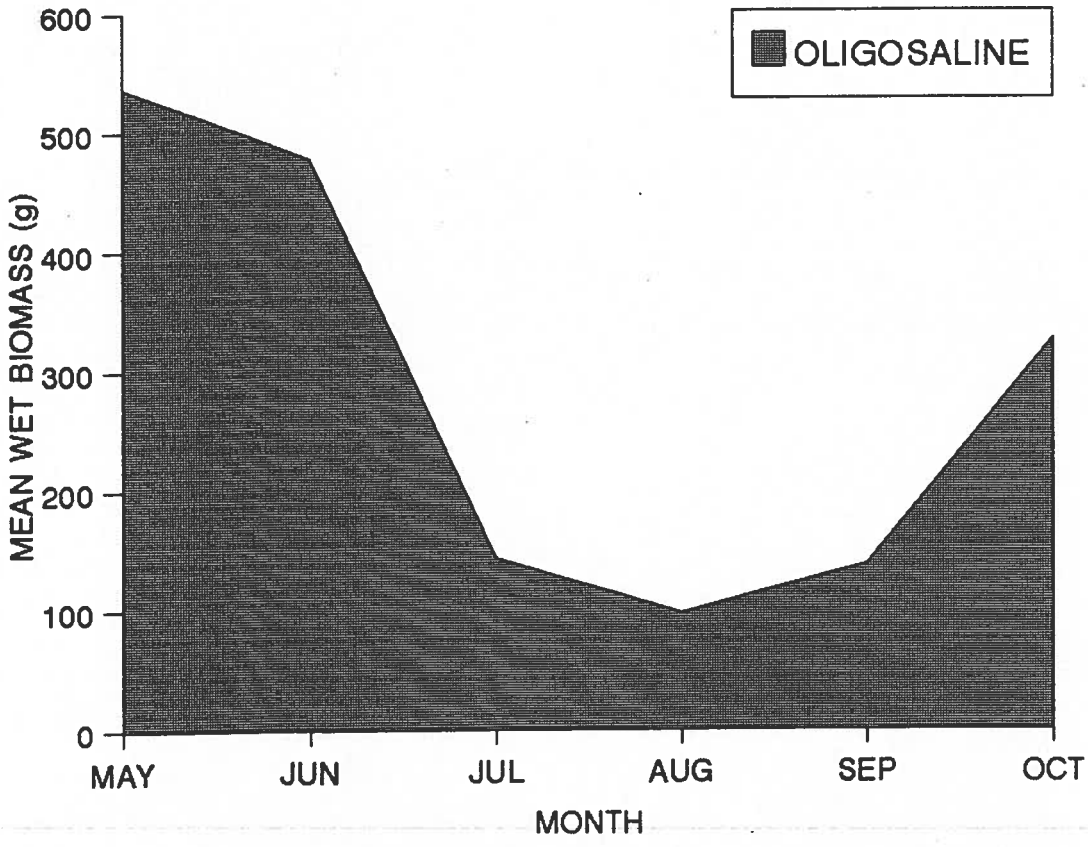
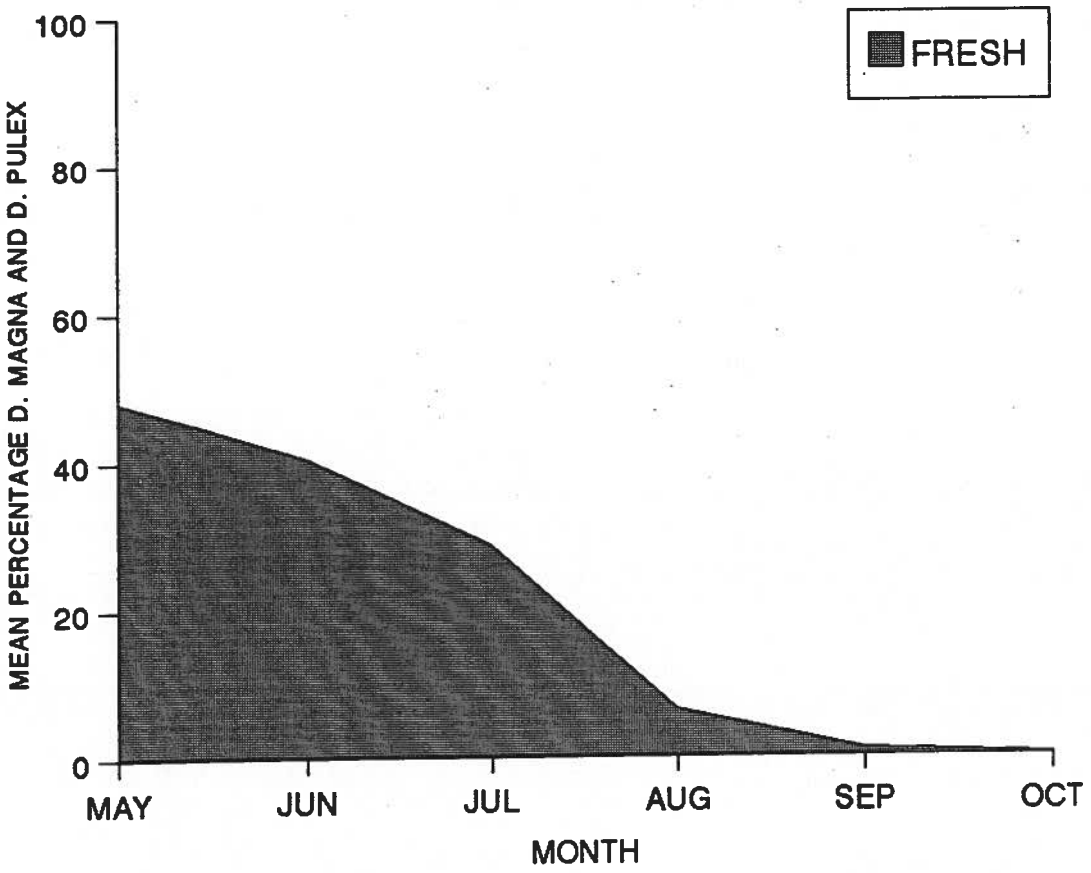


Figure 1. Mean wet biomass collected from Fresh and Oligosaline wetlands.



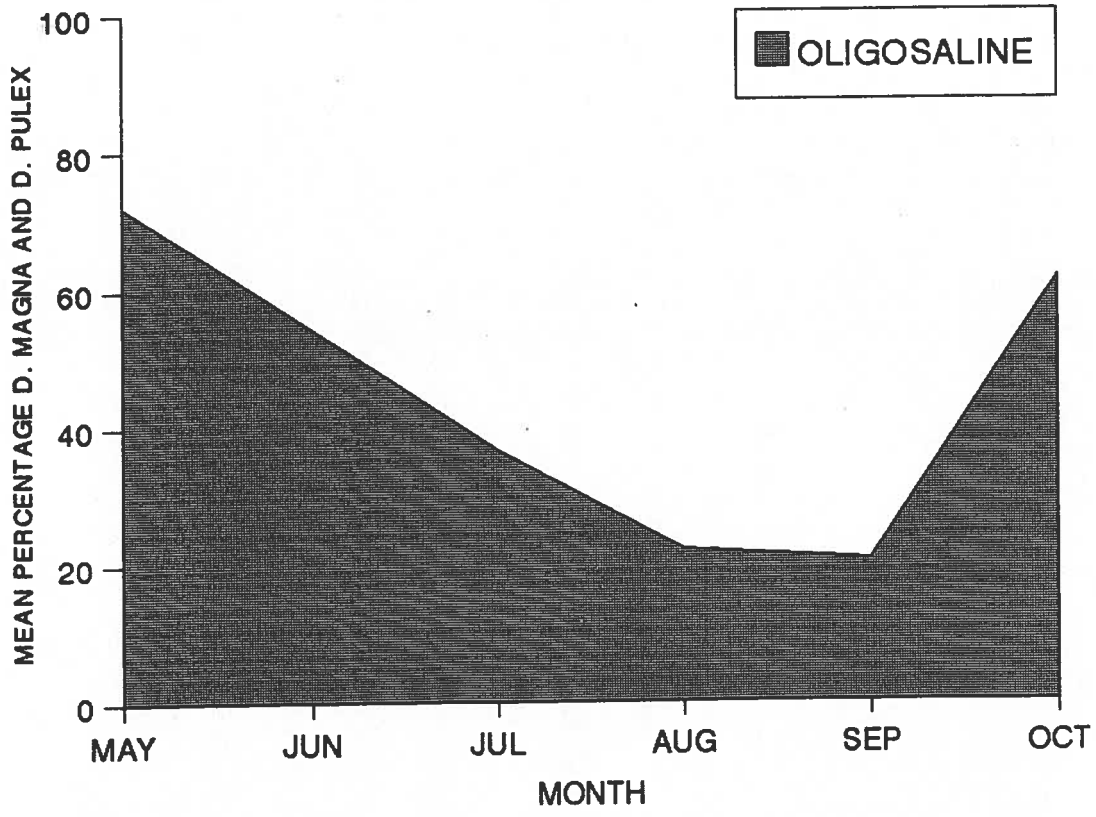


Figure 2. Mean percentage of Daphnia magna and D. pulex collected from Fresh and Oligosaline wetlands, as counted in the laboratory.